Yearlong Current Measurements in Puget Sound's Triple Junction

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[Editor's note: Figures for Nairn et al appear at the end of this paper.]

Abstract
Within Puget Sound, three arms (Admiralty Inlet, Main Basin, Possession Sound) join in a region known as the Triple Junction. To assist in the siting of King County's Brightwater outfall, currents were measured in the Triple Junction from July 2000 to January 2002. All totaled, 56 current meters were deployed for periods of a month or longer.

The current meters were primarily placed along east-west transects to document patterns of currents across the main axes of the Triple Junction. We present an overview of the observed current structure, for both tidal and low-frequency (tidally averaged) currents. Observations included significant horizontal and vertical variations, which are used to suggest some of the underlying mechanisms affecting the circulation in the Triple Junction region.

Introduction
As part of its Regional Wastewater Services Plan, King County plans to construct a new regional wastewater treatment system, the Brightwater Project, in north King County or south Snohomish County by 2010. The wastewater treatment plant will have an outfall in the northern part of Puget Sound between the cities of Shoreline and Edmonds. This region is where Possession Sound joins the Main Basin and Admiralty Inlet, and it is called the Triple Junction. Currents will affect the fate of the discharge from this outfall, but only a few historic current observations were available in this complex region. Thus, the prior understanding of the oceanography of the Triple Junction was insufficient to aid in the site evaluation for King County's proposed wastewater outfall, and a new observational study was carried out during July 2000 through January 2002.

The flow in Puget Sound is dominated by tidal currents, but superimposed on that is a time-varying estuarine circulation caused by the surface outflow of fresh water from river runoff and deep inflow of salt water from the ocean. Amplitudes of the tidal currents in the Main Basin are about 50 cm/s, about half as large as those in Admiralty Inlet and twice as large as those in most of Whidbey Basin. The estuarine circulation is important in transporting water masses and is typically up to about 10 cm/s, but it can be larger during storms and during bottom-water intrusions from Admiralty Inlet.

Most previous studies focused on along-channel effects. The few cross channel studies showed major flow variations that affect how waters mix within the Main Basin. Few studies have been made within the Triple Junction, but they showed unexpected complexity, partly due to the large shoals off Whidbey Island and Point Jefferson and partly due to the confluence of the three major branches. Oceanography reviews of Puget Sound include Cannon (1983), Ebbesmeyer et al. (1984), Bretschneider et al. (1985), Ebbesmeyer et al. (1988), Cannon et al. (1990), Lavelle et al. (1991), Thomson (1994), Matsuura and Cannon (1997), and most recently with respect to the Triple Junction, Ebbesmeyer and Cannon (2001).

The new observations of the oceanography in the Triple Junction were made using several techniques; however, this paper focuses on current meter observations. Additional detail on the observations can be found in King County (2002). Due to the lateral complexity of the Triple Junction, current meter moorings for this study primarily were deployed across channel. Acoustic Doppler Current Profilers (ADCPs) measured currents throughout the water column by transmitting acoustic pulses from instruments sitting on the sea floor. Aanderaa and S4 meters measured currents at specified depths along mooring lines.

Methods

Three types of current meters were used: Aanderaa RCM4s, InterOcean S4s, and Acoustic Doppler Current Profilers (ADCPs). Aanderaa meters mechanically measure currents with a rotor and vane at fixed depths along a mooring line that is anchored to the sea floor. The Aanderaas record on magnetic tape and were loaned to King County for the project. S4s measure currents at fixed points on moorings like the Aanderaas, except that they have no moving parts and sense current speed and direction by water deforming the S4's magnetic field. ADCPs measure currents through the water column using acoustic pulses transmitted from the instrument on the sea floor. They rely on acoustic echoes of pulses from particles suspended in seawater. Water velocities are computed within the ADCP by estimating the differential current speed of the particles between outgoing pulses and returning echoes (Doppler shift). Currents then were subsampled at 10- or 20-m depth intervals, depending on whether the ADCP was for shallow water (300 kHz; two instruments) or deep water (75 and 150 kHz; two each). Additional ADCPs (1500 kHz) were deployed near shore during deployments 5 and 6.

Current meters were deployed for eight intervals lasting one to three months from July 2000 through January 2002. Table 1 summarizes the deployments, and Figure 1 shows the locations. Yearlong moorings were maintained in: (1) Admiralty Inlet to measure deep water inflow using two near-bottom Aanderaa current meters, (2) Possession Sound using two to three Aanderaa meters in the water column with an occasional S4 meter approximately 2 m below the sea surface, and (3) the Main Basin with six Aanderaa meters and an occasional S4 meter.

Table 1. Current Meter Deployment Summary.[1]

Deployment # (location)	Current meter sites	Beginning date	End date	Comments
ADCP moorings				
1 (Edwards Point)	1-6	July 12-13, 2000	August 21-23, 2000	Moorings 1-5, Edwards Point section; Mooring 6, ADCP/Aanderaa comparison
2 (Edmonds)	7-12	August 23-24, 2000	October 30, 2000	Triple Junction section across Whidbey Shoal
3 (Possession Sound and Browns Bay)	13-18	November 2-3, 2000	January 22-23, 2001	Two parallel sections
4 (Point Wells)	19-24	January 25-26, 2001	March 19, 2001	Main Basin Aanderaa mooring
Dye studies	25-28	March 12, 2001	March 21, 2001	Dye studies
5 (Admiralty Inlet)	29-36	March 21-23, 2001	May 14, 2001	Admiralty Inlet and Whidbey Shoal
6 (Point Jefferson)	37-43	May 16-17, 2001	June 19-20, 2001	Southernmost section
7 (Eastern Shore)	44-49	June 21, 2001	July 25, 2001	North-south section to connect the east-west sections
8 (Edwards Point Cluster)	50-53	November 29, 2001	January 8, 2002	ADCP and Aanderaa meters
Aanderaa moorings				
1-7	Possession Sound	July 13, 2000	July 25, 2001	Deployment 5, S4 lost
1-7	Admiralty Inlet	July 12, 2000	July 25, 2001	Deployment 2, mooring lost
1-7	Main Basin	July 13, 2000	July 25, 2001	Deployment 3, 87 m flooded Deployment 5, 177 m failed
8 (Edwards Point)	Mooring 50	November 29, 2001	January 8, 2002	Part of ADCP cluster

[1] See Figure for locations

Observations

Mean currents were computed over 28-day intervals for each current meter record. This interval contains an integer number of tidal cycles, and many historical data have been averaged over this interval.

Figures 2 through 8 show 28-day mean currents perpendicular to seven vertical sections (Figure 1): Point Jefferson, Point Wells, Edwards Point, Edmonds, Browns Bay, Admiralty Inlet, and Possession Sound. Note that the speed scales change from section to section, but the color coding has the same sense: red is the fastest outflow; the transition from yellow to green is the depth of no-net-motion, and blue is the fastest inflow. Blank areas near the surface and bottom occur because the ADCPs cannot determine currents in those regions.

Point Jefferson Section

Figure 2 shows the currents through the section extending southeast from Point Jefferson to Pipers Creek. Northward outflow generally occurred through the section above 40 m except on the eastward site, near Pipers Creek, where weak currents extended down to approximately 90 m. Maximum outflow exceeded 12 cm/s. Mean currents at depth tend to be southeasterly in direction and exceed 10 cm/s with a significant component parallel to this section.

Point Wells Section

A mean current cross-section is shown for the deployment extending westward from Point Wells to the Kitsap Peninsula in Figures 3. The depth of no-net-motion, above which flow is northward, varied from 120 m off Point Wells to the sea surface off the Kitsap Peninsula. The northward outflowing water had a core of higher velocity, exceeding 14 cm/s, centered at Mooring 21. The deep southward inflow had speeds exceeding 16 cm/s concentrated on the west side.

Edwards Point Section

Figure 4 shows currents through the transect extending from near Edwards Point westward to Apple Cove Point on Kitsap Peninsula. As in the Point Wells section, the level of no-net-motion is at the surface near the Kitsap Peninsula and deepens to the east to 140 m off Edwards Point. There is a core of outflowing water exceeding 12 cm/s centered near Mooring 4 on the east side, and the southward inflow exceeds 8 cm/s and is concentrated on the west side. There is a sharp north-south gradient near Mooring 2 between the core of northward outflowing water and the southward inflowing water.

Edmonds Section

The Edmonds section was located between the Admiralty Inlet and Edwards Point sections, crossing Whidbey Shoal at its southern end at Mooring 9. West of the shoal, the level of no-net-motion reached the surface near the Kitsap Peninsula (Figure 5). Northward flow occurred through most of the section over and east of the Whidbey Shoal. The core of the outflowing water was located near mid-channel with mean currents of about 15 cm/s over the shoal. Southward flow occurred close to the Kitsap Peninsula.

Admiralty Inlet Section

Figure 6 shows the mean flow through the section from the Kitsap Peninsula to Whidbey Shoal and then through the north-south section across the shoal to Whidbey Island. Outward flow occurs across the entire section, above 80 m on the western side, above 50 m nearer Whidbey Shoal, and at all depths over the shoal. The core of high northward velocity, exceeding 10 cm/s, occurred at mid channel, and the highest inflow, exceeding 14 cm/s, also occurred at mid channel in the deepest portion of the section. During a second month of observations (April – May) the mean flow was 25-50% weaker than the first month.

Browns Bay Section

This section extended from Browns Bay on the east, then trend northwest to Whidbey Shoal. Figure 7 shows the 28-day average of along-channel speed, illustrating that the currents are weak and variable, flowing toward the north and south and alternating across the section. The strongest northward currents occur in a core just east of Whidbey Shoal, and near the bottom off Browns Bay. Between the two bands of northward currents, the currents flow southward along the eastern slope of Whidbey Shoal and near the mid-portion of the section.

Possession Sound Section

Figure 8 show the 28-day mean current for measurements made at the Possession Sound section. Three depth layers are evident. The upper layer consists of a southerly flow of fresher water out of Whidbey Basin. Much of this layer is less than 20 meters thick and was not captured by the ADCP current meters, but was captured by the S-4 meter, shown in

Figure 9. The largest currents appear to be in the thickest part of the upper layer toward the western shore along Whidbey Island. This outflow appears to go around the end of Whidbey Island and across the shoal, as seen in the shallow outflow in the Admiralty Inlet section.

The middle layer flows into Possession Sound in the general depth range from 40 m to approximately 140 m. The largest inflow occurred beneath the largest outflow in the upper layer (western side) reaching speeds of 5 cm/s. The third and deepest layer flows out of Possession Sound at depths greater than approximately 140 m.

Discussion

The most prominent features of the observed flow field are the maximum velocity in inflowing water deep along the Kitsap coastline, and the shallower outward flowing water with a velocity maximum that tends towards the eastern side of Puget Sound. These have the same tendency as expected from the Coriolis force, but are also influenced by the geometry of the Triple Junction and the converging/diverging flows between Admiralty Inlet, Possession Sound, and the Main Basin.

It is often useful to create simplified pictures, or schematics, of the overall circulation. These schematics describe the general pattern of circulation and how this pattern tended to vary under different conditions. The circulation within Puget Sound and the Triple Junction region is complex, and the limited sampling window of this study cannot adequately detail longer term variability, so these pictures are limited to providing a general view of the circulation. To this extent, the observations from the current meters at fixed locations and from drifters (drift cards, drogues, dye) were combined to create schematics of the mean flow and the associated variability.

Figures 10 and 11 are schematic presentations of the dominant mean flow patterns in the outflowing layer near the sea surface and in the mid depth inflowing layer in the Triple Junction. The shallower map is above the depths of the Whidbey and Jefferson shoals and represents the near-surface flow. The deeper map is below the depth of the shoals. In the Main Basin this layer primarily is inflowing bottom water, but in some locations it also includes outflowing water or a transition between inflowing and outflowing. In Possession Sound this layer is the dominant inflow level.

This study has provided significant additional observations on the physical oceanography of Puget Sound focused on the Triple Junction region. Deployments of current meters in a cross-channel pattern have provided significant additional information on the complex flow patterns of this region. Further information on this study and the observational results can be found in the report King County, 2002.

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Figures

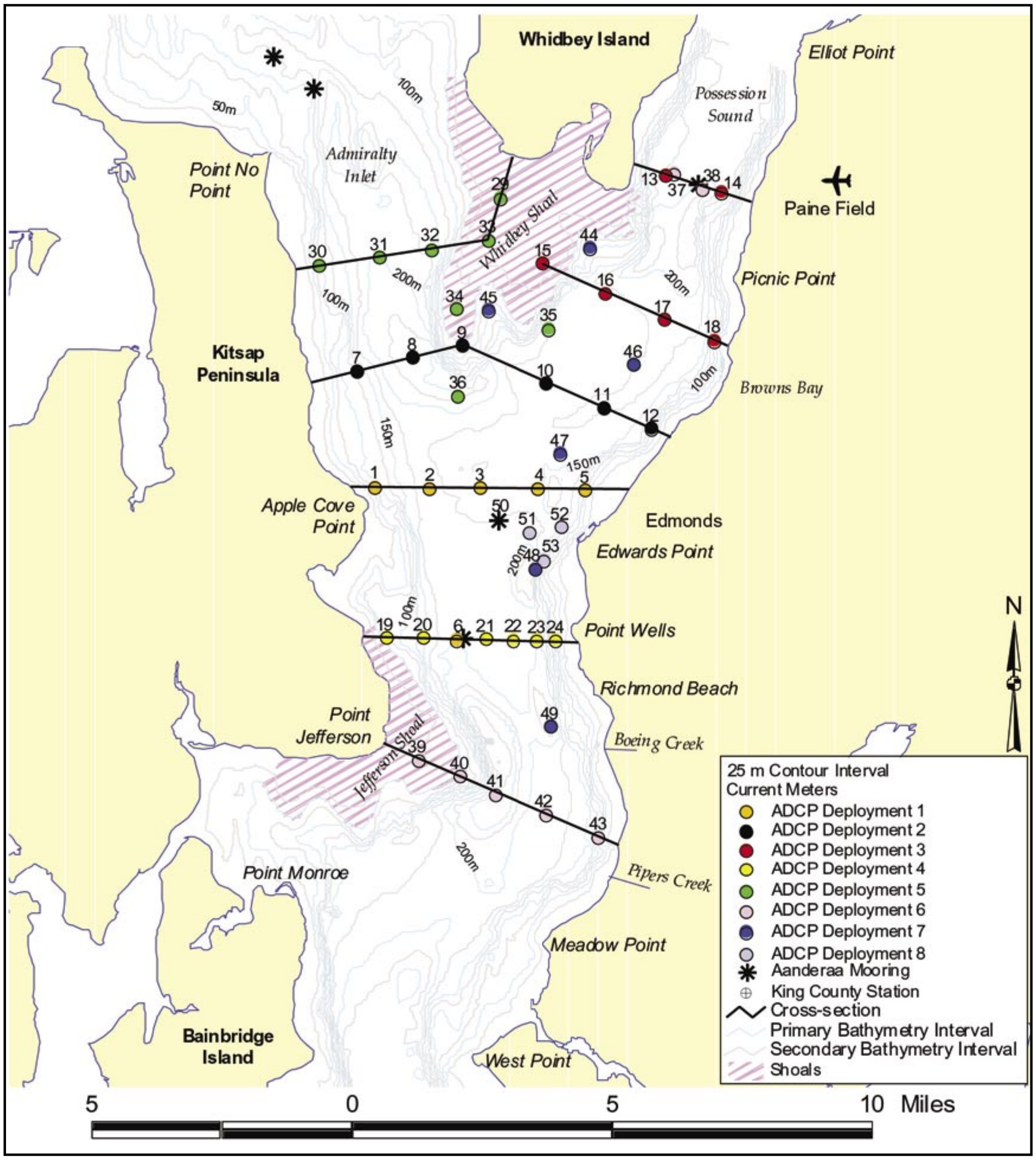

Figure 1. Current meter mooring locations. Numbers are the label given to each station. Stations identified with the same colors were deployed concurrently.

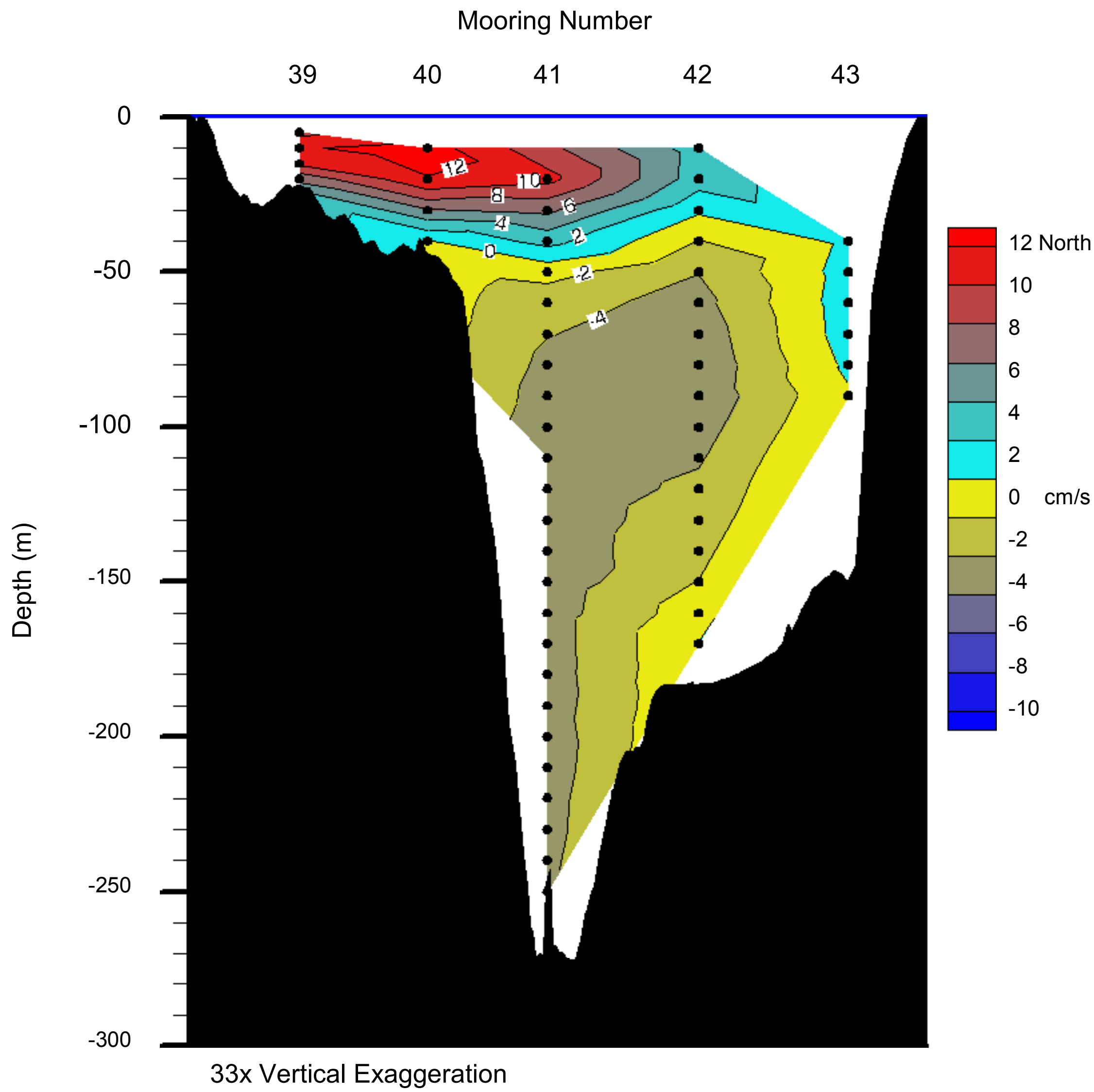

Figure 2. 28-day mean currents through the section extending southeast from Point Jefferson to Pipers Creek. Red is the fastest outflow; blue is the fastest inflow.

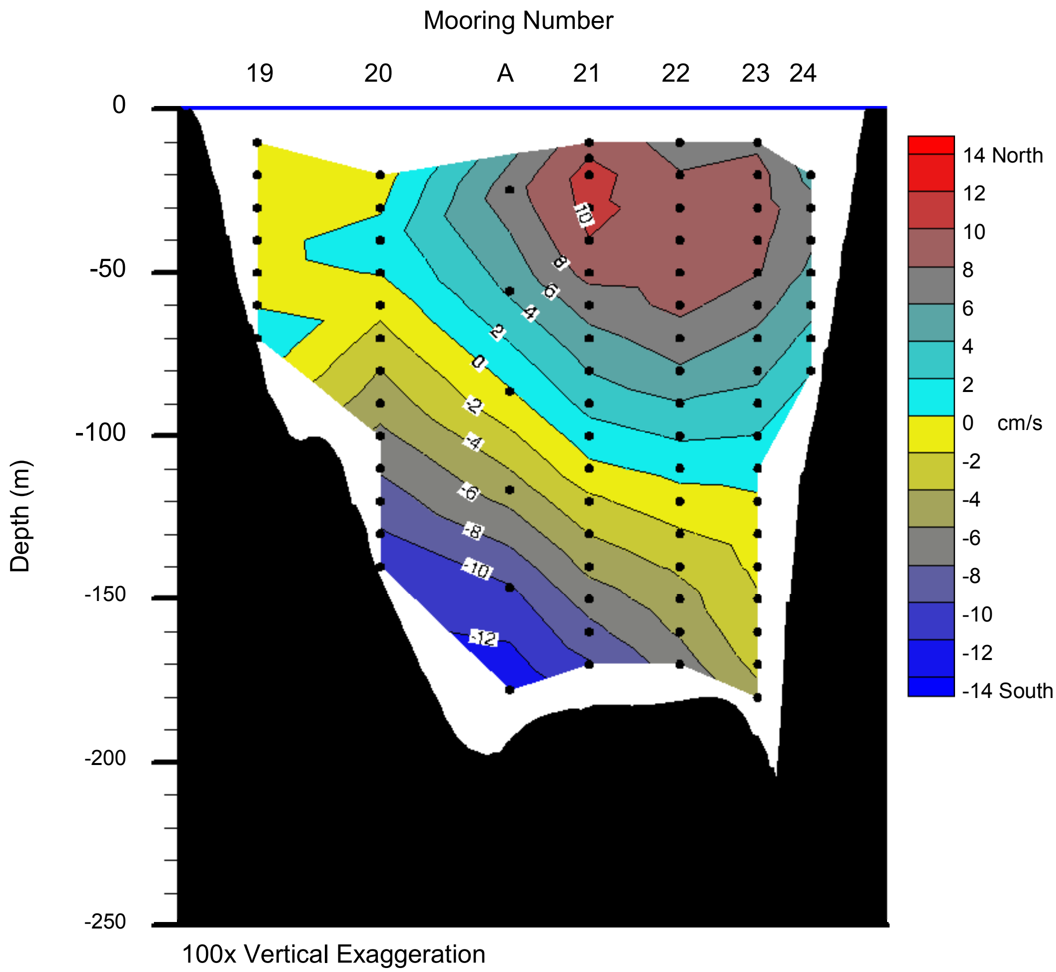

Figure 3. 28-day mean currents through the section extending west from Point Wells. Red is the fastest outflow; blue is the fastest inflow.

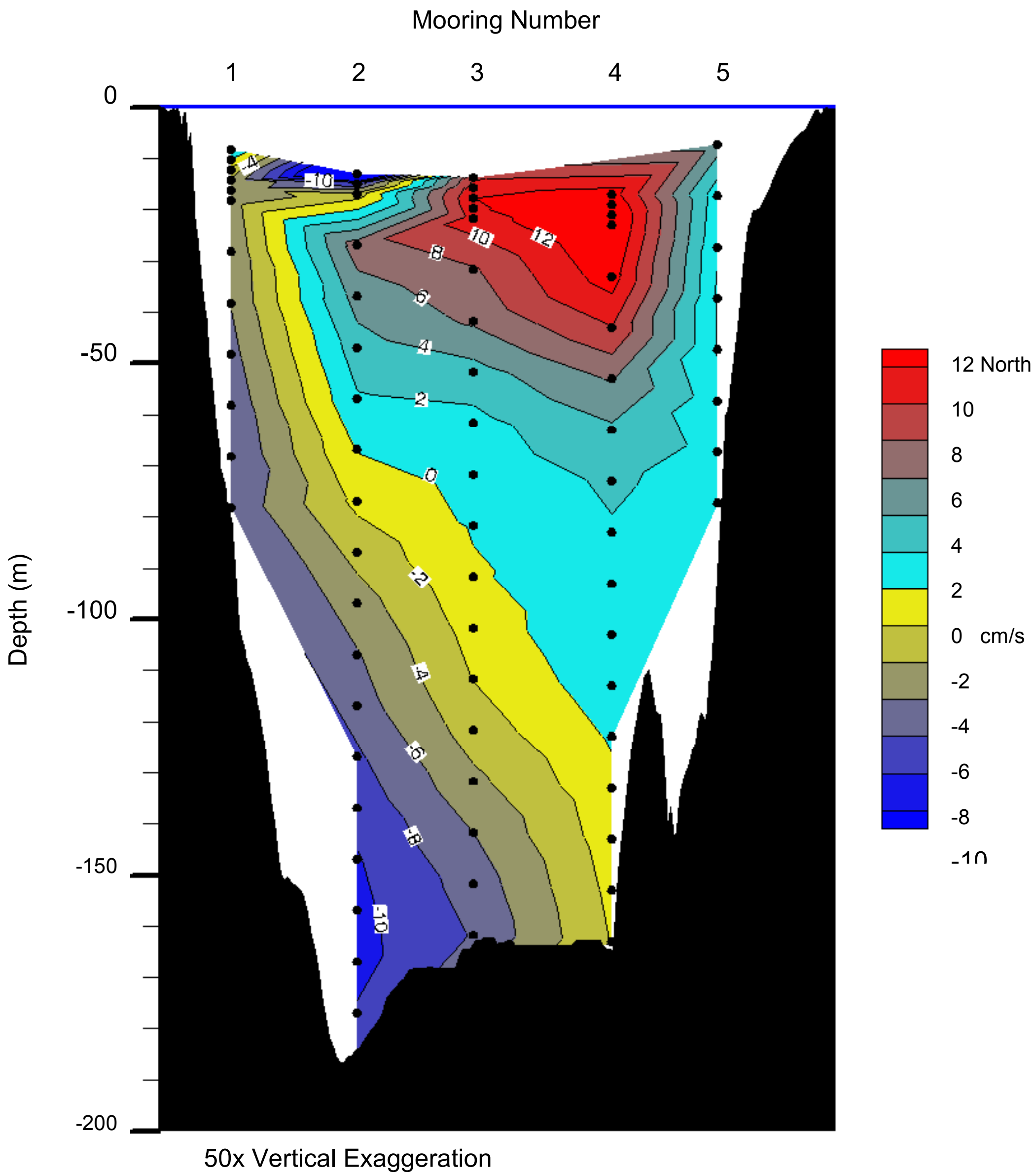

Figure 4. 28-day mean currents through the section extending west from Edwards Point. Red is the fastest outflow; blue is the fastest inflow.

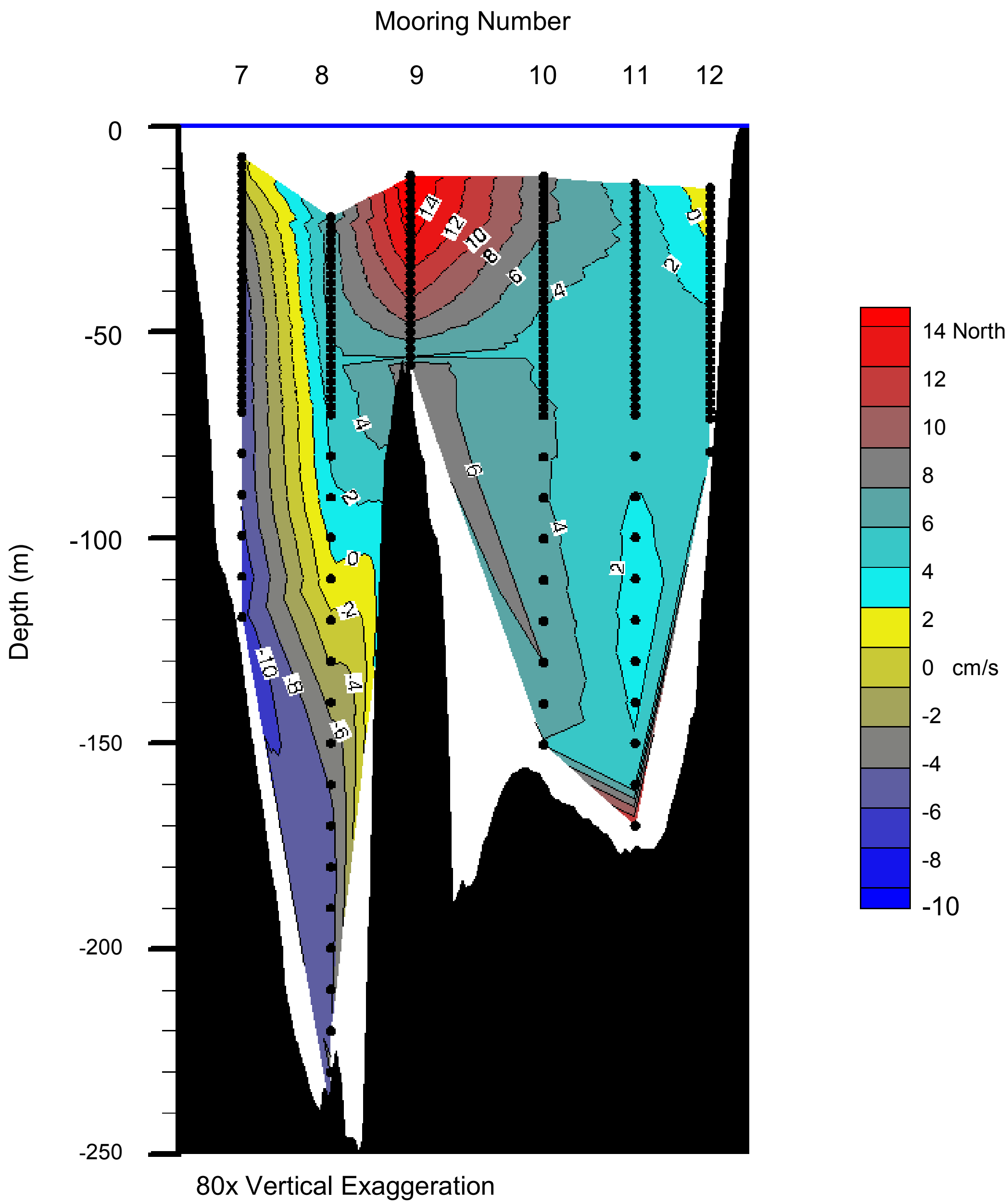

Figure 5. 28-day mean currents through the section extending west from Edmonds. Red is the fastest outflow; blue is the fastest inflow.

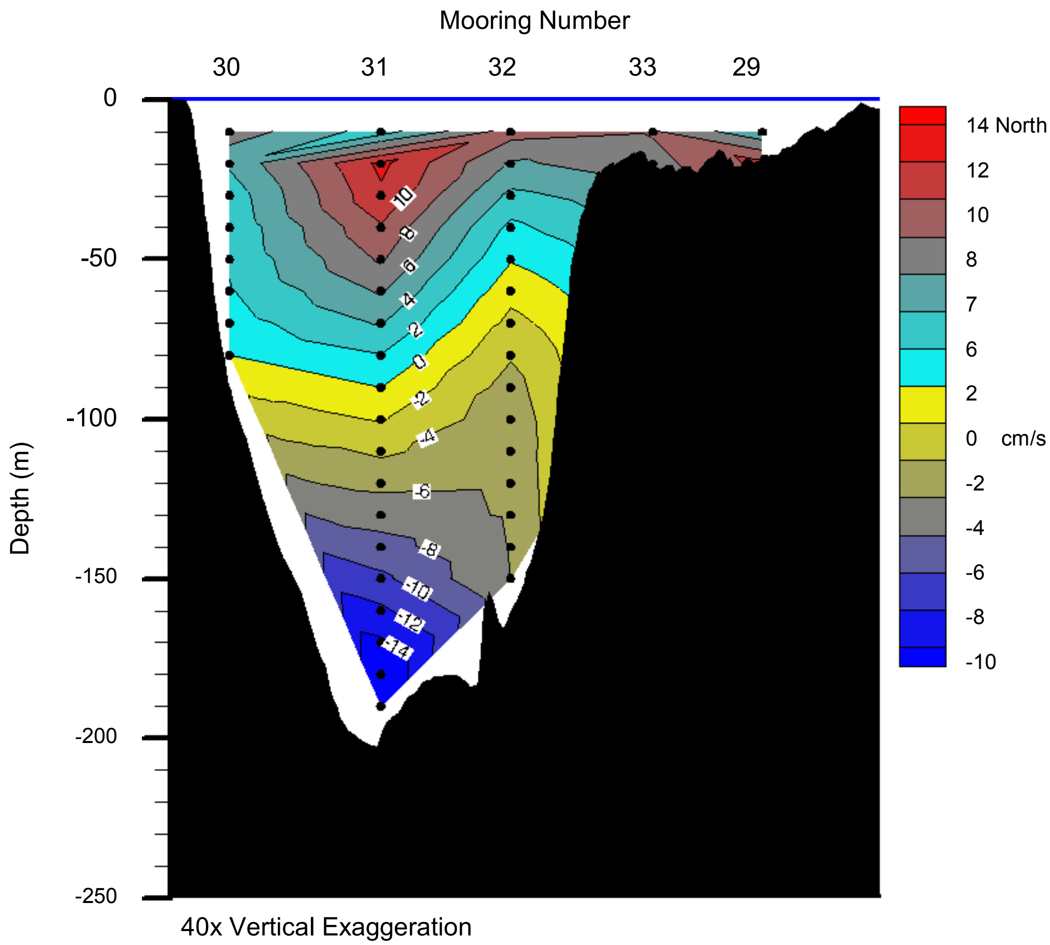

Figure 6. 28-day mean currents through the section extending across from Admiralty Inlet. Red is the fastest outflow; blue is the fastest inflow.

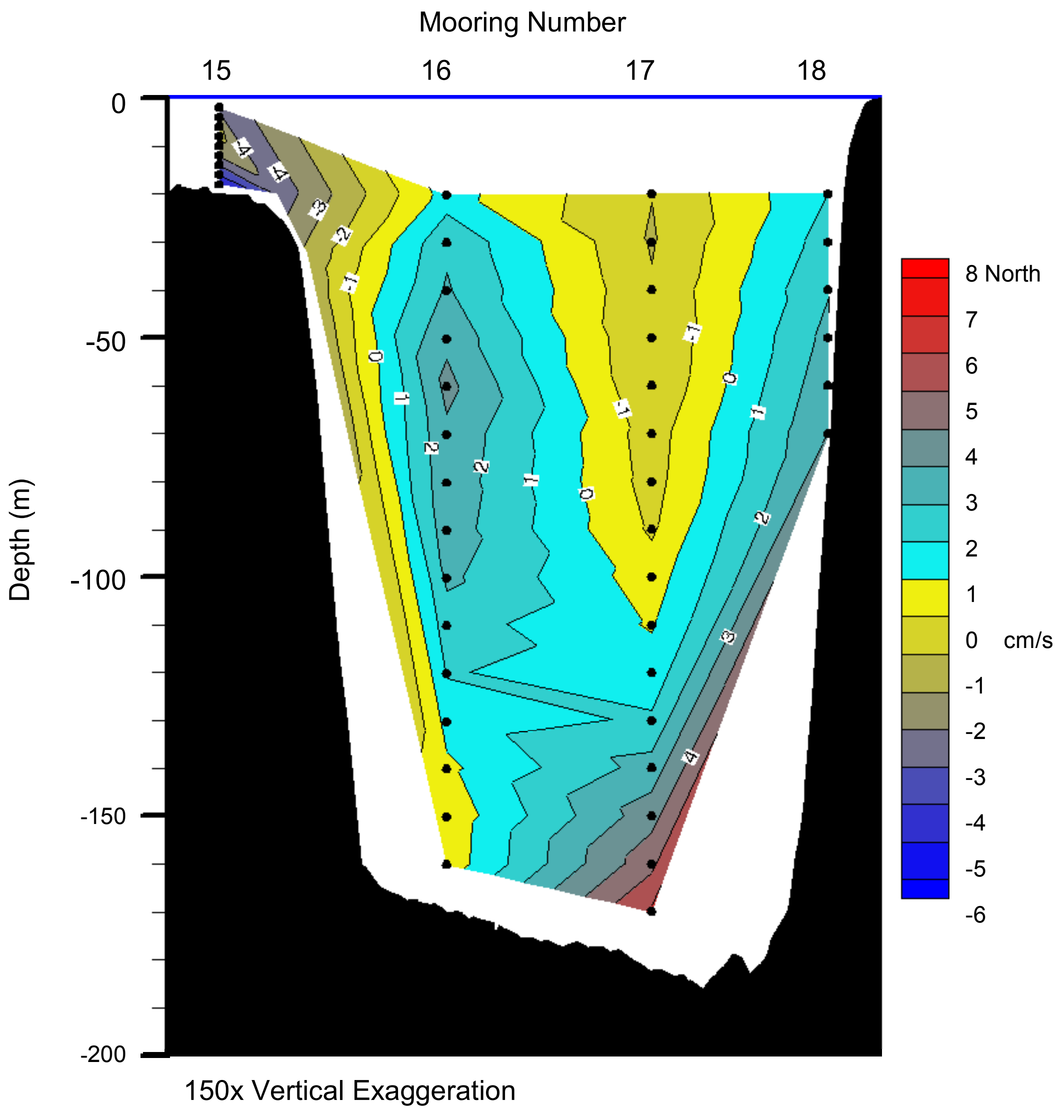

Figure 7. 28-day mean currents through the section extending west from Browns Bay. Red is the fastest outflow; blue is the fastest inflow.

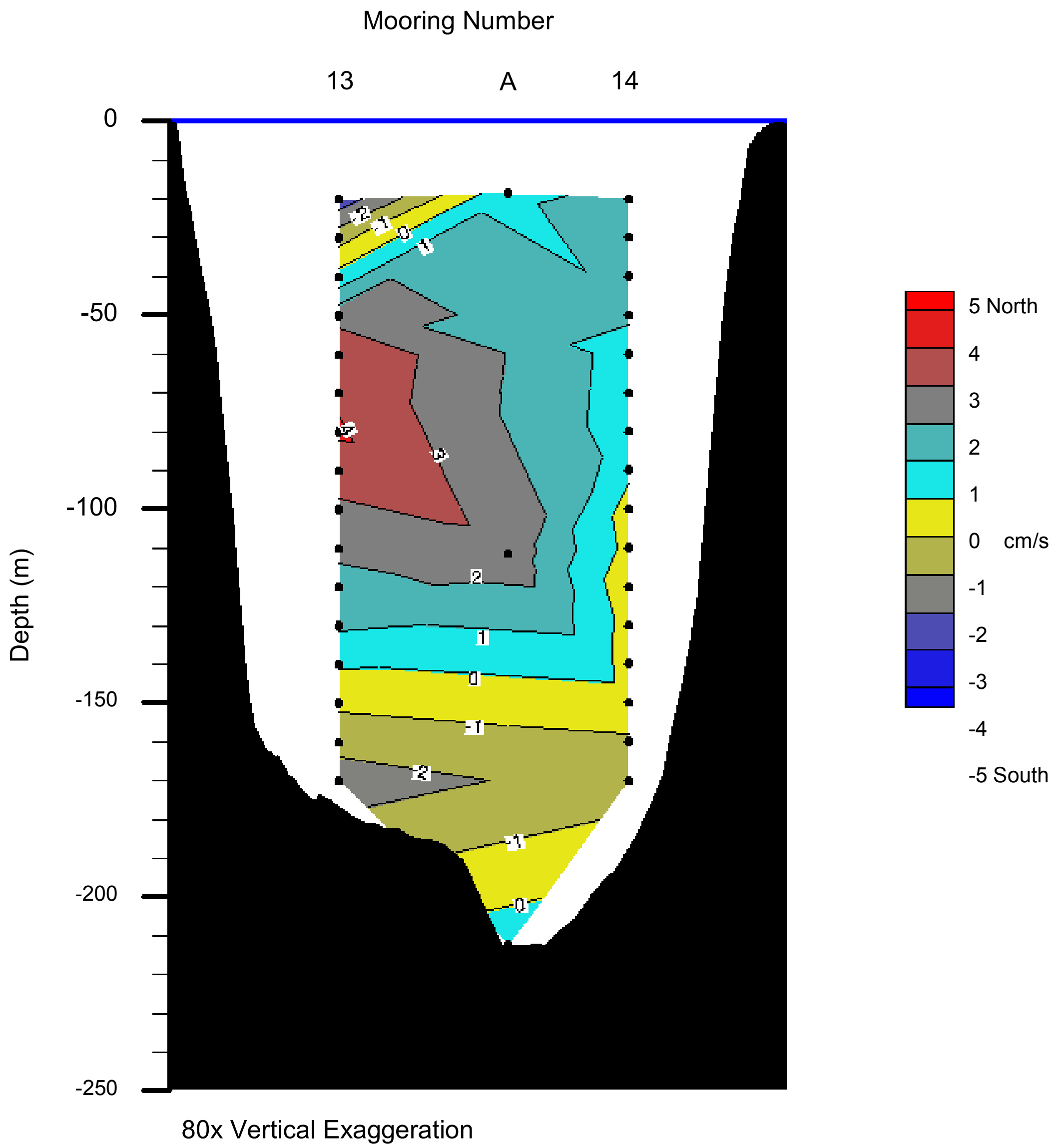

Figure 8. 28-day mean currents through the section extending across Possession Sound. Red is the fastest outflow; blue is the fastest inflow.

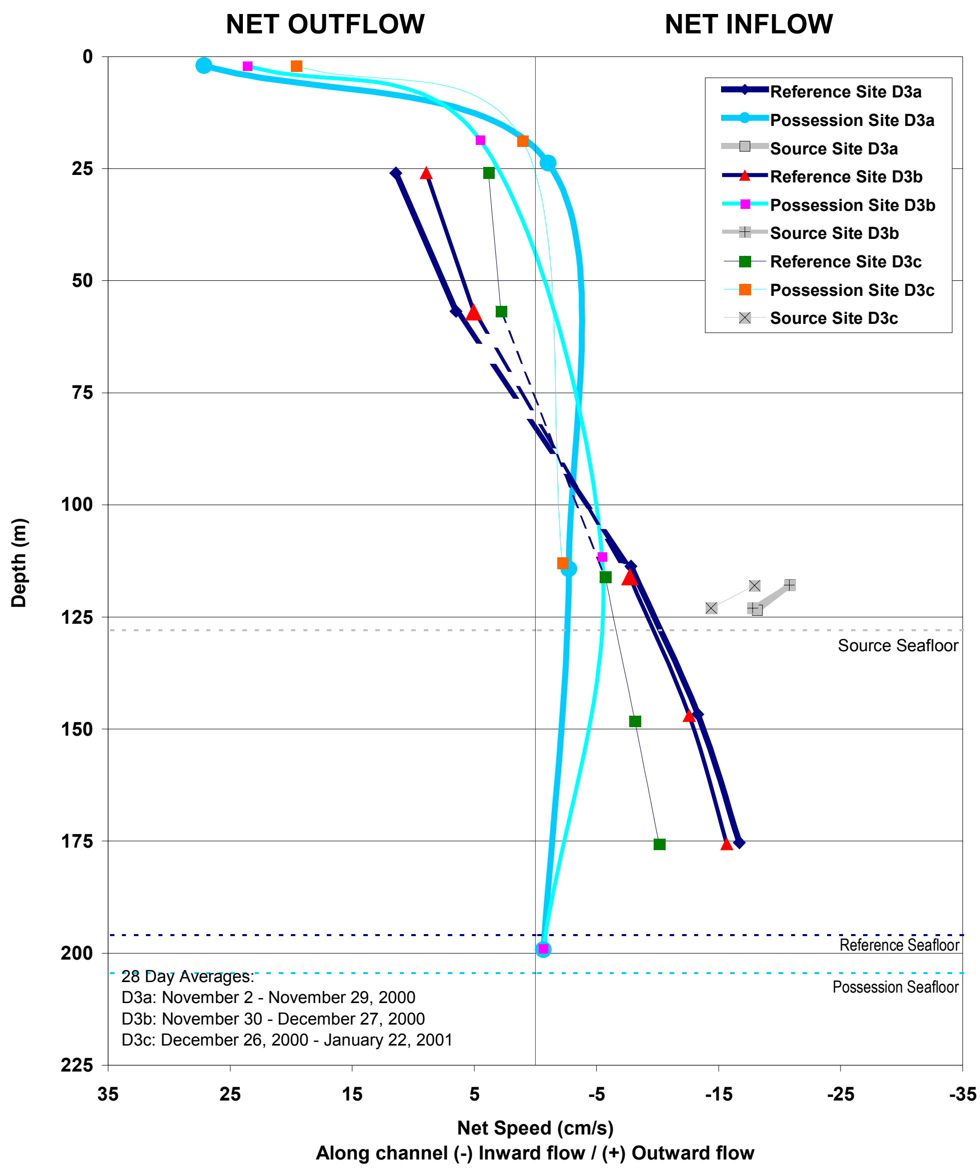

Figure 9. 28-day mean currents obtained from the Aanderaa and S4 current meters located in Admiralty Inlet (grey lines, "source site"), Possession Sound (light blue) and the Main Basin (dark blue). The S4 meter captures a strong outflow from Possession Sound that is poorly resolved the ADCP data.

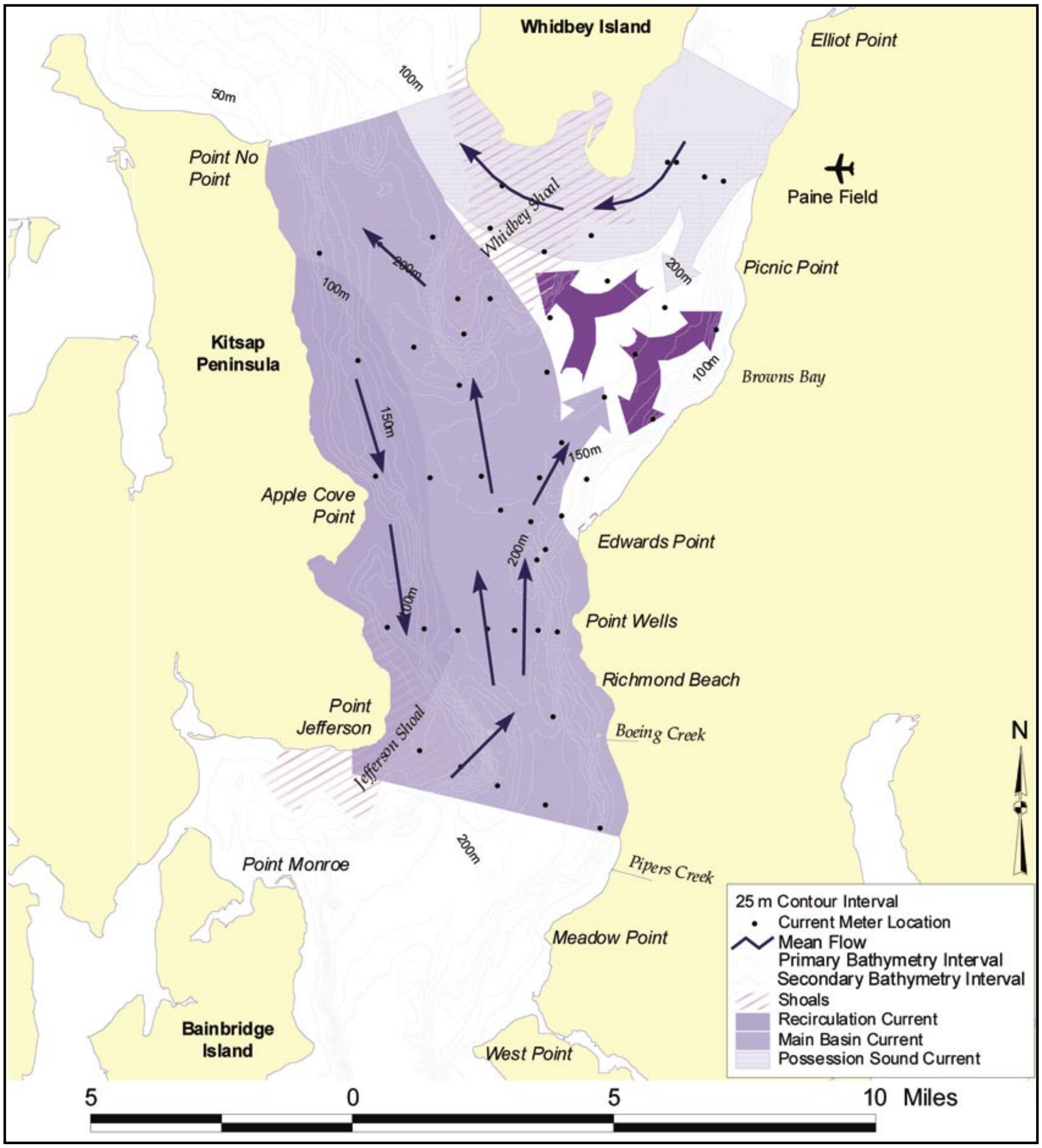

Figure 10. Conceptual flow pattern within the Triple Junction at depths above the shoals (roughly 20 meters). The current in the main basin flows southward along the western coast, more strongly northward along the eastern coast. A region of convergence and diverence occurs around Brown's Bay, and an outflowing layer of water comes south from Possession Sound, flowing westward over the sill south of Widbey Island.

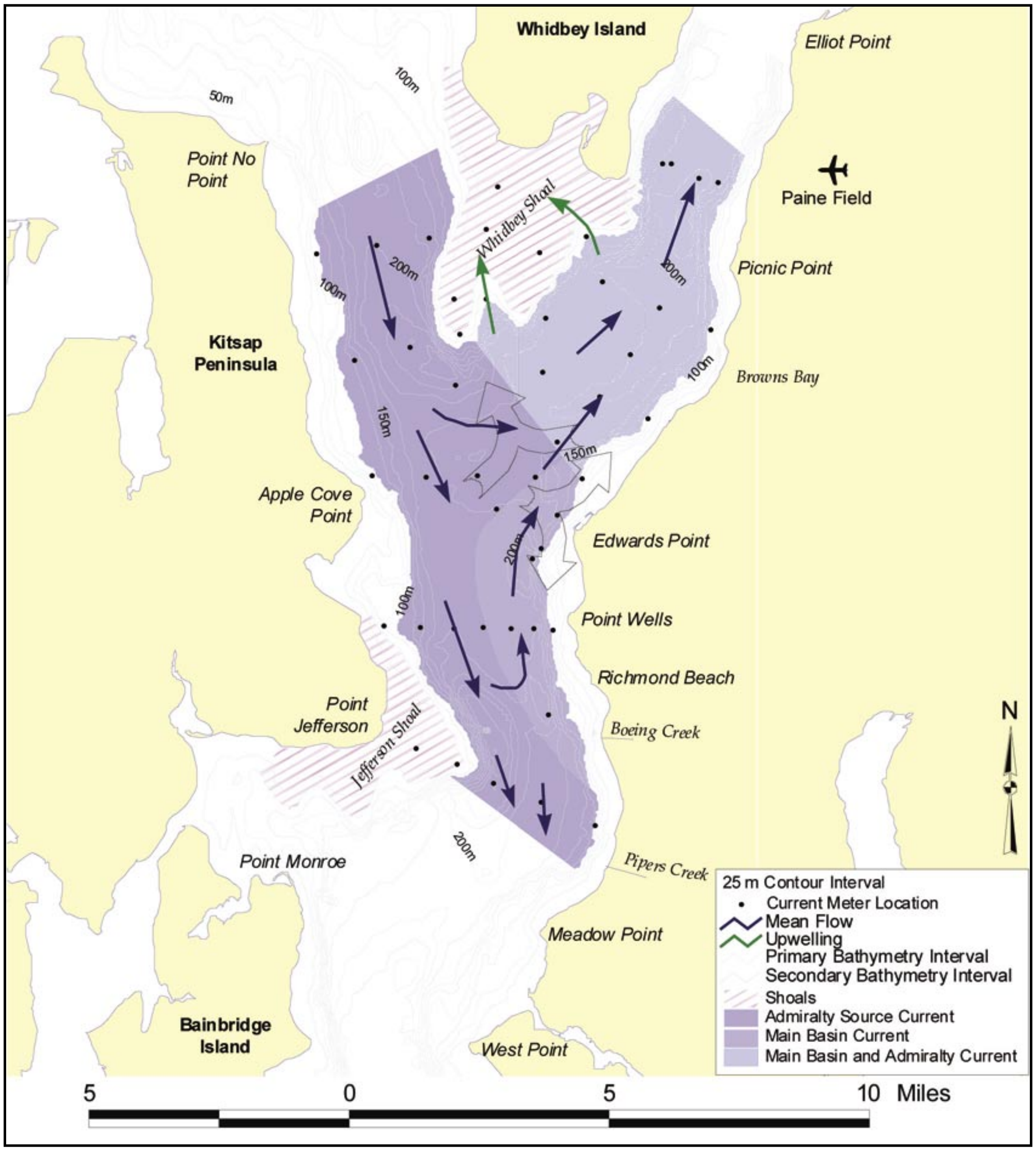

Figure 11. Conceptual flow pattern within the Triple Junction at depths below the shoals (roughly 100 meters). The current in the main basin flows strongly southward along the western coast, northward along the eastern coast. A region of convergence and diverence occurs around Edwards Point, and a weak mean flow moves northward into Possession Sound. Upwelling was indicated over Whidbey Shoal by lagrangian drifters.